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Remediation Technologies in the U.S.: Current Practice and New Developments

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1. ABSTRACT

Seventeen years ago, federal legislation—Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)—created a national program to clean up about 1300 significant abandoned hazardous waste sites in the United States. Also known as Superfund, this law spurred the development of more than forty state clean-up programs to respond to thousands of other sites; subsequently, Congress created programs to deal with releases of contaminants from currently operating industrial facilities and with leaking underground tanks—primarily from petroleum hydrocarbons. As of 1998, much progress has been made in cleaning up sites identified in the Superfund program. The 500th site was completed in December 1997. Corrective action is complete at tens of thousands of leaking underground tanks.

Many of the technologies being used today did not exist in the waste management context 15 years ago. As a supplement to traditional incineration and solidification and stabilization technologies, new chemical, physical, and biological technologies have been developed, demonstrated, and commercialized. Over 250 full-scale demonstrations of remediation technologies have been completed in North America. About 300 innovative treatment technology projects are in design, being constructed, or completed in the Superfund program alone. Thousands of underground storage tank sites have used newer approaches to deal with this specialized type of contamination. In addition, there are several new technology adaptations and developments to deal with difficult contamination problems, such as chlorinated solvents. This paper provides an overview of the demonstration and deployment of new remediation technologies in the United States and North America, and will discuss in more detail new techniques being developed and used to address chlorinated solvent contamination.

2. INTRODUCTION

Over the last seventeen years, a diverse and mature group of technologies to remediate contaminated soil and groundwater has developed in the United States. Three different federal clean-up programs have spurred the development of these technologies. In response to a growing concern about contaminated sites, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1980. The law, commonly known as Superfund, established a trust fund based on taxes on the petroleum and other basic organic and inorganic chemicals, and provided broad federal authority to respond to releases or threatened releases of hazardous substances that may endanger public health or welfare, or the environment. In 1986, the Superfund law was amended, increasing the trust fund considerably - to $8.5 billion over five years. For fiscal year (FY) 1998 alone, Congress authorized a Superfund budget of $2.1 billion, almost double that of FY 1997. However, the availability of $650 million of this budget is contingent on reauthorization of the Superfund law this year.

Hazardous sites are assessed and ranked before being placed on the Superfund National Priorities List (NPL). For the 1,345 locations that have been listed on the NPL, cleanup decisions have been made for 885 sites. In the past five years, 70% of all Records of Decision [RODs are formal documents required under administrative law] for source control involve a provision for treatment of some portion of the waste. Construction was completed in December 1997 at the 500th Superfund site.

The second major clean-up program directed the remediation of releases from a population of two million active and closed underground storage tanks. Over 300,000 tanks have confirmed releases; an estimated 100,000 additional tanks will leak in the future. With oversight by the States, owners and operators have contracted with the engineering community to clean up petroleum hydrocarbon releases from these tanks. Over the last six years, the States have overseen the cleanup of releases to soil and groundwater from some 250,000 tanks. These activities have created a major supply of specialized technologies for this contaminant and typical site size.

The final clean-up program was directed at the conduct of corrective action at currently operating industrial facilities. In contrast to Superfund (which was largely directed at abandoned waste sites), the Resource Conservation and Recovery Act of 1980 and its subsequent amendments largely affect industrial facilities with waste management activities—both current and in the past.

All three of these programs and their site types also are problems at federal facilities—particularly those of the Departments of Defense and Energy. These remediation programs are financed by the separate budgets of these Departments, not by Superfund. In addition, these Departments have created technology development and evaluation programs to target their own unique clean-up problems.

3. BACKGROUND FOR TECHNOLOGY DEVELOPMENT

Inadequacies in available methods and the need for more cost effective technologies in the Superfund program led to a statutory mandate for demonstration of technologies in the 1986 amendments to the original law. In the next 10 years, as the number of sites moved from a study phase to the clean-up phase, the supply of technologies grew and diversified. Most of the technologies being used today did not exist in the waste management context 15 years ago. In some cases, technologies from other industrial sectors have been adapted to use in the clean-up context (e.g., soil washing, horizontal wells, bioremediation). In others, totally new approaches have been developed only for contaminated soil and groundwater (e.g., treatment walls, soil vapor extraction).

In each case, the supply of technologies was both assisted and hindered by the remediation context. The 1986 Superfund amendments required treatment to the maximum extent practicable and reduction in the toxicity, mobility, or volume of the waste. The prospect of new business opportunities in remediation—a market driven by regulation—caused a positive response from the developers of technologies. On the other hand, in addition to the normal risks of technology commercialization, this market was complicated by the liabilities embedded in the clean-up laws in the event that the technology made the situation worse. There were numerous disincentives for site owners, consulting engineers, remediation service providers, and others to try out new technologies.

EPA's role in technology development also has changed in the last seven years. The Agency is no longer strictly the regulatory "driver" with the treatment preferences noted earlier. Nor is it only the technology demonstration agent, as mandated in the 1986 Superfund amendments. Its more expansive role is that of advocate and collaborator with the private sector (especially site owners) and other government agencies to develop partnerships to pursue new technologies for difficult problems.

4. TECHNOLOGIES IN THE SUPERFUND PROGRAM

EPA has made considerable progress in encouraging the development of new treatment technologies as alternatives to conventional approaches, and in selecting innovative methods. Three hundred innovative projects are underway in the Superfund program (Figure 1). The selection of these processes surpassed conventional technologies (i.e., incineration and solidification and stabilization) for the first time during fiscal year 1993 (October, 1992 to September, 1993).

The selection and use of remediation technologies in the Superfund program provides an indication of their commercial availability and acceptability in the marketplace. In the Superfund program, the number of times established technologies have been chosen or used for soil has decreased in recent years (Figure 3). Even the selection of the three most common innovative technologies has leveled off (Figure 4). Overall, the trend is toward more cost-effective in situ technologies, which in general are applied to much larger volumes of soil than ex situ methods. Figure 5 generally shows a preference for in situ processes as the volume of soil increases. Innovative technologies used at Superfund sites typically have been applied to organic contamination; there are few alternatives to solidification/stabilization available for metals (Figure 6). Even in the case of organic compounds, only one of the methods more often used, bioremediation, actually destroys the contaminant; the others are separation and concentration techniques. For groundwater remediation, the vast majority of remedies (93%) involve pump-and-treat (Figure 7). In situ technologies, primarily air sparging and bioremediation, are becoming more widely used.

5. COMPLETED DEMONSTRATIONS OF CLEAN-UP TECHNOLOGIES

An important factor in the introduction of new technologies to the buyers and the engineering community has been the availability of cost and performance data from full-scale projects. Several national demonstration programs developed over the last 17 years, in addition to the seminal effort authorized by the Superfund law in 1986.

5.1 Completed Demonstration Projects in North America

As of 1996, over 300 field demonstrations of innovative remediation technologies have been completed in North America. Most of these demonstration projects were performed or funded by EPA, the U.S. military services (Army, Navy, and Air Force), the U.S. Department of Energy, the government of Canada, and the state of California. Of these, the Air Force has completed 123 bioventing[1] and 16 bioslurping[2] demonstrations at facilities across the U.S. The other 259 projects are summarized in Figure 8. Almost 200 of the 259 projects inventoried deal with soil media. About one quarter of the projects were demonstrations of biological processes. Currently half of the projects are in situ, reflecting recent interest in technologies to treat soil and groundwater in place.

5.2 Superfund Innovative Technology Evaluation (SITE) Program

The 259 demonstration projects discussed above include those conducted under the Superfund Innovative Technology Evaluation (SITE) program. Authorized by the 1986 amendments, the SITE program represents a major agency effort to aid commercialization. SITE primarily conducts full-scale field evaluations of innovative technologies developed by private vendors. The program develops credible cost effectiveness information so that decision makers can choose the technology with confidence in its performance. Over 100 technologies are participating in the demonstration program, with 85 field efforts already completed (Figure 9). Seventy-three technologies at earlier stages of development participated in the emerging (laboratory- and pilot-scale) part of the program. Although no longer operating, this program provided limited funding for the early stages of technology development. SITE plays an important role by raising the awareness of decision makers about the potential benefits of innovative technologies, and provides credible information to allow innovative technology decisions to be made with confidence.

6. PROMISING DEVELOPMENTS IN REMEDIATION OF CHLORINATED SOLVENTS

Past industrial practices (for instance, dry cleaning, degreasing) in the U.S. have led to a large number of sites contaminated with chlorinated solvents. Almost 65% of NPL sites are

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[1]Bioventing stimulates in situ biodegradation of aerobically degradable compounds in soil by providing oxygen (usually through air injection and/or extraction) to existing soil microorganisms. It uses low air flow rates to provide only enough oxygen to sustain microbial activity and inhibit contaminant removal by volatilization.

[2]Bioslurping is the simultaneous application of bioventing of vadose zone soils and free product or light, non-aqueous phase liquid (LNAPL) from groundwater. Vacuum-enhanced pumping allows LNAPL to be lifted off the water table without extracting large quantities of groundwater.

contaminated with these compounds (Figure 10). The most common, trichloroethylene, requires remediation at half of all sites, and the second most frequent, tetrachloroethylene, requires cleanup at over one-third of NPL sites (Figure 11).

The most common practice for extracting solvents in soil is soil vapor extraction (SVE). SVE can be used in tandem with air sparging to address solvents in groundwater. These technologies are removal, not destruction, techniques, and therefore require subsequent treatment of extracted vapors. In addition, despite their success at mass removal of solvents, they do not apply at every site. Thus, several other promising technologies are being developed and demonstrated to deal with volatile compounds. SVE, air sparging, and other techniques being used or developed to treat solvents in the saturated and unsaturated zones are described below.

Until recently, many believed that contaminants in surface soils were the only significant source of groundwater contamination. We now realize that non-aqueous phase liquids—both lighter than water (LNAPLs) and denser (DNAPLs)—form pools of immiscible liquid and serve as major sources of contamination. Unless all sources of contamination are removed, classical pump and treat systems may only contain the problem.

This recognition has heightened awareness of the need to focus research efforts on the problems of locating and treating or removing LNAPLs/DNAPLs in groundwater. Examples of processes that are being investigated to improve recovery and removal of contaminants include hydrofracturing, air sparging, directional wells, and hot water or steam flushing/stripping. Various biological processes are being investigated for providing in situ treatment, including oxygen enhancement with hydrogen peroxide and air sparging, co-metabolic processes, nitrate enhancement, and anaerobic degradation. In addition, permeable reaction walls are being developed to provide treatment of contaminated plumes. These techniques are described further below.

6.1 Contaminant Removal

Soil Vapor Extraction (SVE). SVE may be the technology that comes closest to being a universal solution for volatile organic compounds (VOCs) in the field of hazardous waste remediation. In its simplest application, SVE involves installing wells in the contaminated vadose (unsaturated) zone and the use of vacuum pumps to extract volatile contaminants. The first step up from basic SVE adds air injection wells to increase air flow and the rate of volatilization. SVE has been used to remediate thousands of underground storage tank (UST) releases and is being applied increasingly to chlorinated organic solvent releases. The latest Technology Innovation Office (TIO) annual report on the status of innovative treatment technologies indicates a total of 139 Superfund remedial actions involving SVE with 18 completed projects (Figure 1).

As an in situ technology that does not require excavation or materials handling (e.g., sizing and crushing), SVE can be as much as 30-40% cheaper than competing ex situ approaches. Additional advantages of SVE include minimal exposure to the public and workers, and minimal disruption of surface activities. Also, from the standpoint of technology development, as a ‘core’ technology, SVE acts as a platform which developers can enhance with related technologies.

Interesting adaptations building on this core technology include air sparging, bioventing, horizontal wells, pneumatic and hydraulic fracturing, and subsurface heating.

Multiphase Extraction (MPE). This technique is a modification of conventional SVE. MPE simultaneously extracts both groundwater and soil vapor. The groundwater table is lowered in order to dewater the saturated zone; the SVE process is then applied to the newly exposed soil. Soluble VOCs in the extracted groundwater are removed above-ground.

One interesting application of MPE is being tested by the McClellan Partnership Groundwater Workgroup, a partnership of state and federal agencies and the private sector. The Partnership is investigating and evaluating the XEROX-patented two-phase extraction system, designed to remove VOCs from groundwater more cost-effectively than conventional pump-and-treat approaches. A high-vacuum pump extracts large volumes of both contaminated groundwater and soil vapor simultaneously through a single extraction well. As the water phase moves up the well, turbulence causes dissolved contaminants to enter the vapor phase. The resulting water phase can be easily treated above ground using carbon polishing before discharge.

Air sparging. Air sparging extends the reach of SVE into the saturated zone to remove contaminants from groundwater. Injection of air below the water table serves as a form of in situ air stripping. As a technique, air sparging is usually initiated after a period of SVE in the vadose zone to create the desired pressure gradients and flow patterns.

Horizontal wells. Another SVE adaptation involves the use of advances in directional drilling technology to install horizontal wells instead of traditional vertical SVE wells. Advantages of horizontal wells include a much greater radius of influence, thus requiring fewer wells and reducing costs, and the ability to remove contamination under buildings and structures where excavation would be infeasible. EPA has completed one Superfund cleanup utilizing horizontal wells; this approach is being aggressively explored by the Department of Energy. An interesting aspect of the EPA Superfund cleanup was that the contractor was able to operate the equipment via telemetry from their home office hundreds of miles away.

Pneumatic/Hydraulic Fracturing. Used in low permeability soils, these processes create conductive channels in the formation. These channels increase the permeability and exposed surface area of the soil, accelerating removal and treatment of the contaminants.. Pneumatic fracturing involves the injection of highly pressured air to extend existing fractures and create a secondary fracture network. Hydraulic fracturing involves the injection of gel pumped at high pressure into the borehole to propagate the fracture. The gel biodegrades, leaving highly permeable sand-filled lenses that may be up to 60 feet in diameter.

Subsurface Heating. A class of SVE enhancements can be grouped under the concept of adding additional energy to the subsurface to increase the rate of contaminant recovery and/or to allow recovery of semi-volatile contaminants, which might not be amenable to basic SVE. Examples include hot air injection, radio-frequency heating and steam injection. DOE’s Lawrence Livermore laboratory completed a successful demonstration of a dynamic stripping technology to treat groundwater by combining SVE with steam injection and direct electrical resistance heating of saturated clay layers. In 10 weeks of operation, over 7,400 gallons of gasoline were removed from 100,000 cubic yards of soil at a cost of $50/cubic yard.

6.2 Contaminant Destruction

Bioventing/bioremediation. Bioremediation involves the use of microorganisms such as bacteria or fungi supplemented as necessary with oxygen, nutrients, and sometimes co-metabolites, to transform hazardous chemicals into less toxic or non-toxic chemicals. Because SVE removes contaminants and transports them to the surface, it requires off-gas treatment which can be expensive. Bioventing involves air injection coupled with a slower rate of extraction in the hope that microorganisms (usually indigenous) will degrade the contaminants. An additional potential benefit of bioventing is the ability to remediate non-volatile and low-volatility hydrocarbons such as fuel oil and diesel fuel.

Bioremediation of chlorinated solvents requires a co-metabolite, such as toluene, methane, or propane. The enzymes produced for oxidation of the co-metabolite or primary substrate are then capable of degrading the chlorinated solvents or secondary substrate. Two demonstrations of cometabolic bioventing of TCE are planned in 1998 under a public-private partnership called the Remediation Technologies Development Forum (RTDF). In the case of bioremediation of groundwater, the addition of methane or methanol supports methanotrophic activity, which as been demonstrated to effectively degrade chlorinated solvents, such as vinyl chloride and TCE, by co-metabolism. This process is anaerobic (i.e., takes place in the absence of oxygen). This year, the RTDF successfully demonstrated methanotrophic bioremediation of perchloroethylene and TCE in groundwater at Dover Air Force Base in Delaware. Further information on several RTDF projects can be found on the Internet at <www.rtdf.org>.

Bioslurping is the simultaneous application of bioventing of vadose zone soils and free product or light, non-aqueous phase liquid (LNAPL) from groundwater. Vacuum-enhanced pumping allows LNAPL to be lifted off the water table without extracting large quantities of groundwater.

Phytoremediation. This technique uses plants to remediate environmental media in situ. It includes rhizofiltration (absorption, concentration, and precipitation of heavy metals by plant roots), phytoextraction (extraction and accumulation of contaminants in harvestable plant tissues such as roots and shoots), and phytotransformation (degradation of complex organic molecules to simple molecules). One application of phytoremediation that is generating considerable interest is the use of trees as a solar-driven natural pump-and-treat system to control the migration of and remove chlorinated solvents from groundwater. Poplars and cottonwoods are promising trees for this application because the extend their roots to the water table and pump from the saturated zone. They also are fast-growing (3-5 meters/year). In April 1996 almost 700 cottonwood trees were planted at Carswell Air Force Base in Texas to clean up shallow TCE-contaminated groundwater. Early results 1-1/2 years later indicate that, while the trees are pumping groundwater, they have not yet begun to hydraulically control the contaminant plume. Other efforts include a recently-created RTDF subgroup that is focusing on this application of phytoremediation, as well as the use of plants to control infiltration of water into landfills (i.e., evapotranspirative caps).

Treatment Walls. Also known as passive barriers or passive treatment walls or trenches, an in-ground trench is backfilled with reactive media to provide treatment of contaminated groundwater passing through the trench. The wall is placed at strategic locations to intercept the contaminant plume and backfilled most frequently with zero-valent iron. The iron creates very reducing conditions, resulting in hydrogen generation. Dissolved chlorinated solvents (ethenes, ethanes, and methanes) are chemically degraded at relatively rapid rates. Other treatment processes which occur within the treatment wall include sorption and precipitation. Research and demonstrations are focusing on materials to treat chlorinated solvents, chromium, uranium, polynuclear aromatic hydrocarbons (PAHs), and radionuclides. Also being studied are installation methods and degradation rates for the treatment material. To date, installations are complete for four pilot-scale and four full-scale projects. Over 14 full-scale systems are scheduled to be installed in the next year.

7. TECHNOLOGY INFORMATION

The fast pace of remediation technology development makes it difficult to keep up with the latest data on cleanup technologies. A number of published and electronic resources are available to access current information. Several of these sources are described below. A more detailed list of documents, and order information, are provided in the next section.

7.1 WASTECH Monographs

WASTECH was established by the American Academy of Environmental Engineers (AAEE) to create engineering monographs on site clean-up technologies. The monographs were written by expert task groups established by the Academy. Phase I documents provide detailed, state-of-the-practice engineering monographs on eight clean-up technologies (bioremediation, chemical treatment, soil washing/soil flushing, solvent/chemical extraction, stabilization/ solidification, thermal desorption, thermal destruction, and vacuum vapor extraction) to assist site managers and permit writers in the selection and implementation of the technologies. The Phase II series, nearing completion, provides design and application guidance in seven volumes. (Solvent extraction and soil washing have been combined into a single, *Liquid Extraction* manual.)

7.2 Vendor Information System for Innovative Treatment Technologies

Many new technology developers as well as potential users lacked profile information about the nature of the vendor community and its capabilities. TIO has created a microcomputer-based, menu-driven database called the Vendor Information System for Innovative Treatment Technologies (VISITT). VISITT allows potential technology users to stay informed of the capabilities of the rapidly growing supply of private vendors. The fifth version of this database, contains information on 346 processes offered by 210 vendors. Ten thousand copies of VISITT have been distributed free of charge upon request in over 60 countries. The updated inventory shows over one third of vendors with in situ-processes, and bioremediation technologies comprising the largest single overall category (38%) (Figure 12). The sixth version of VISITT will be available in early 1998.

7.3 Federal Roundtable Cost and Performance Data

The selection and use of more cost-effective cleanup remedies requires better access to publicly-available data on the performance and cost of technologies used in the field. To make data more widely available, member agencies of the Federal Remediation Technologies Roundtable are working jointly to publish case studies of full-scale remediation and demonstration projects. Six volumes of case studies, and two volumes of abstracts are now available. The case studies are also searchable on the Internet at <www.frtr.gov>.

7.4 SITE Program Technology Profiles

The Superfund Innovative Technology Evaluation (SITE) Program, now in its tenth year, is an integral part of EPA's research into alternative cleanup methods for waste sites. Under the SITE program, EPA enters into agreements with technology developers, who further develop and/or demonstrate their technologies with support from EPA. The *SITE Program Technology Profiles, 9th Edition*, (EPA-540-R-97-502) describes each of the 190 cleanup and 28 measurement/monitoring technologies in the program. Each profile describes the technology; its applicability to various wastes; development or demonstration status; demonstration results, if available; and technology contacts. The Profiles are on-line at <www.epa.gov/ORD/SITE>.

7.5 Electronic Information

<u>Clean-Up Information (CLU-IN) Homepage</u>. The "CLU-IN" Homepage is a World Wide Web site that allows hazardous waste cleanup professionals to communicate and exchange information. It contains a variety of information about site remediation that is accessible in computer files or databases. The CLU-IN Internet World Wide Web site is at http://clu-in.com. To access CLU-IN by modem, call (301) 589-8366 (8 data bits, 1 stop bit, no parity, vt-100 or ansi). The telnet address is clu-in.epa.gov. Voice help is available by calling (301) 589-8368. The CLU-IN homepage also links to related web sites, such as the Ground-Water Remediation Technologies Analysis Center homepage at http://www.gwrtac.org. This site contains recent information on the development of innovative technologies to remediate groundwater.

<u>TechDirect</u>. TechDirect is a monthly e-mail service to keep subscribers abreast of new EPA and other agency publications and events of interest to site remediation and site characterization professionals. To subscribe:

- Send an e-mail message to "listserver@unixmail.rtpnc.epa.gov"
- Please do not include a subject line in your message; you may add a period"." if your mailserver requires an entry.
- The body of your message should say: *subscribe techdirect* firstname lastname
- TIP: Please have your Postmaster exclude "techdirect@unixmail.rtpnc.epa.gov" from your AutoResponder if you are using one

<u>Federal Remediation Technologies Roundtable (FRTR) Homepage</u>. This homepage, at <www.frtr.gov>, contains products developed jointly by member federal agencies, including remediation case studies described above, and the *Remediation Technologies Screening Matrix and Reference Guide, 3rd Edition*. This guide describes the treatability and treatment methods for

eight classes of chemical contaminants; contains profiles on 64 technology categories, more than 200 technology variations; and provides relative ratings of the 64 technologies on nine key factors, including developmental status and overall cost.

8. FOR ADDITIONAL INFORMATION

8.1 Technology Innovation Office Documents

The following documents and databases produced by the Technology Innovation Office of the U.S. Environmental Protection Agency provide additional information on the programs described in this paper. They are available from:

National Center for Environmental Publications and Information (NCEPI)
11029 Kenwood Road, Building 5
Cincinnati, Ohio 45242
Phone: 513-489-8190
Fax: 513-489-8695

- U.S. EPA (1996), Bibliography on Cleanup of Contaminated Soil and Ground Water, EPA-542-B-96-003

- U.S. EPA (1996), Innovative Treatment Technologies: Annual Status Report, 8th Edition,, EPA-542-R-96-010 and ITT Database, version 2.0

- U.S. EPA (1997), SITE Program Technology Profiles, 9th Edition, EPA-540-R-97-502

- U.S. EPA (1994), Vendor Information System for Innovative Treatment Technologies (VISITT), version 5, U.S. Environmental Protection Agency,

- U.S.EPA (1995), Remediation Case Studies, Volume 1: Bioremediation, EPA-542-R-95-002

- U.S.EPA (1995), Remediation Case Studies, Volume 2: Groundwater Treatment, EPA-542-R-95-003

- U.S.EPA (1995), Remediation Case Studies, Volume 3: Soil Vapor Extraction, EPA-542-R-95-004

- U.S.EPA (1995), Remediation Case Studies, Volume 4: Thermal Desorption, Soil Washing, and In Situ Vitrification, EPA-542-R-95-005

- U.S.EPA (1995), Remediation Case Studies, Volume 5: Bioremediation and Vitrification, EPA-542-R-97-7-008

- U.S.EPA (1995), Remediation Case Studies, Volume 6: Soil Vapor Extraction and other In Situ Technologies, EPA-542-R-97-009

- U.S.EPA (1995), Abstracts of Remediation Case Studies, Volume 1, EPA-542-R-95-001

- U.S.EPA (1997), Abstracts of Remediation Case Studies, Volume 2, EPA-542-R-97-010

The WASTECH monographs listed below are available for the fee indicated from:

American Academy of Environmental Engineers
130 Holiday Court, Suite 100
Annapolis, MD 21403
Phone: 410-266-3311
Fax: 410-266-7653

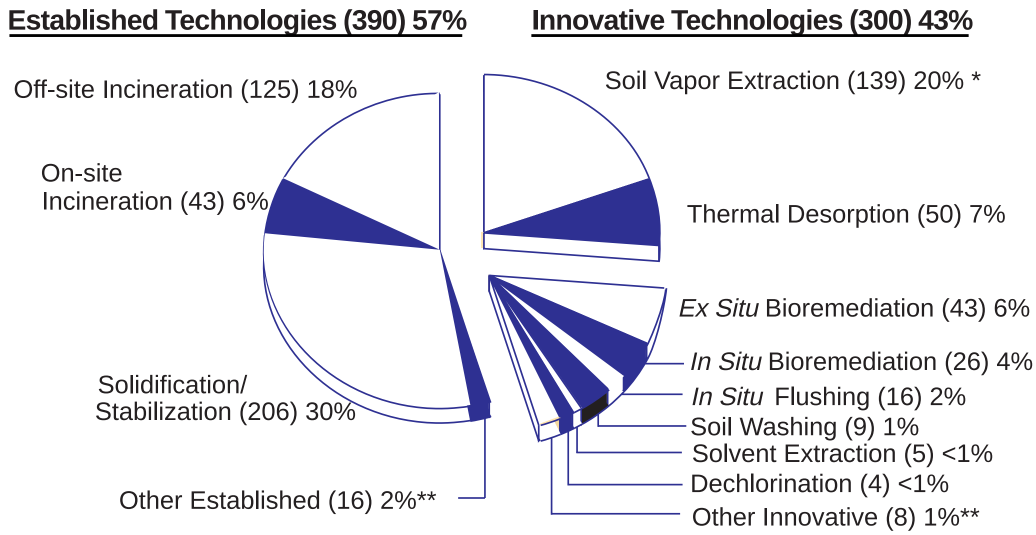
The following Phase I volumes published in are available from AAEE for $59.95 individually, or $393.00 for the entire set, plus shipping and handling:

Innovative Site Remediation Technology: Bioremediation (Volume 1), 1995
Innovative Site Remediation Technology: Chemical Treatment (Volume 2), 1994
Innovative Site Remediation Technology: Soil washing/Soil flushing (Volume 3), 1993
Innovative Site Remediation Technology: Solidification/Stabilization (Volume 4), 1994
Innovative Site Remediation Technology: Solvent/Chemical Extraction (Volume 5), 1995
Innovative Site Remediation Technology: Thermal Desorption (Volume 6), 1993
Innovative Site Remediation Technology: Thermal Destruction (Volume 7), 1994
Innovative Site Remediation Technology: Vacuum Extraction (Volume 8), 1995

The following Phase II volumes published in 1997 are available for prices ranging from $74.70 to $94.70 per volume, plus shipping and handling:

Innovative Site Remediation Technology: Chemical Treatment, Design and Application
Innovative Site Remediation Technology: Stabilization/Solidification, Design and Application
Innovative Site Remediation Technology: Thermal Desorption, Design and Application

Figure 1. Superfund Remedial Actions: Summary of Source Control Treatment Technologies Selected Through Fiscal Year 1995



Notes:

* Includes two dual-phase extraction projects also listed as *in situ* groundwater technologies.

** "Other" established technologies: soil aeration, open detonation, and chemical neutralization. "Other" innovative technologies: physical separation, contained recovery of oily wastes (CROW™), cyanide oxidation, vitrification, hot air injection, and plasma high-temperature metals recovery.

Figure 2. Superfund Remedial Actions: Number of Established vs Innovative Treatment Technologies for Source Control

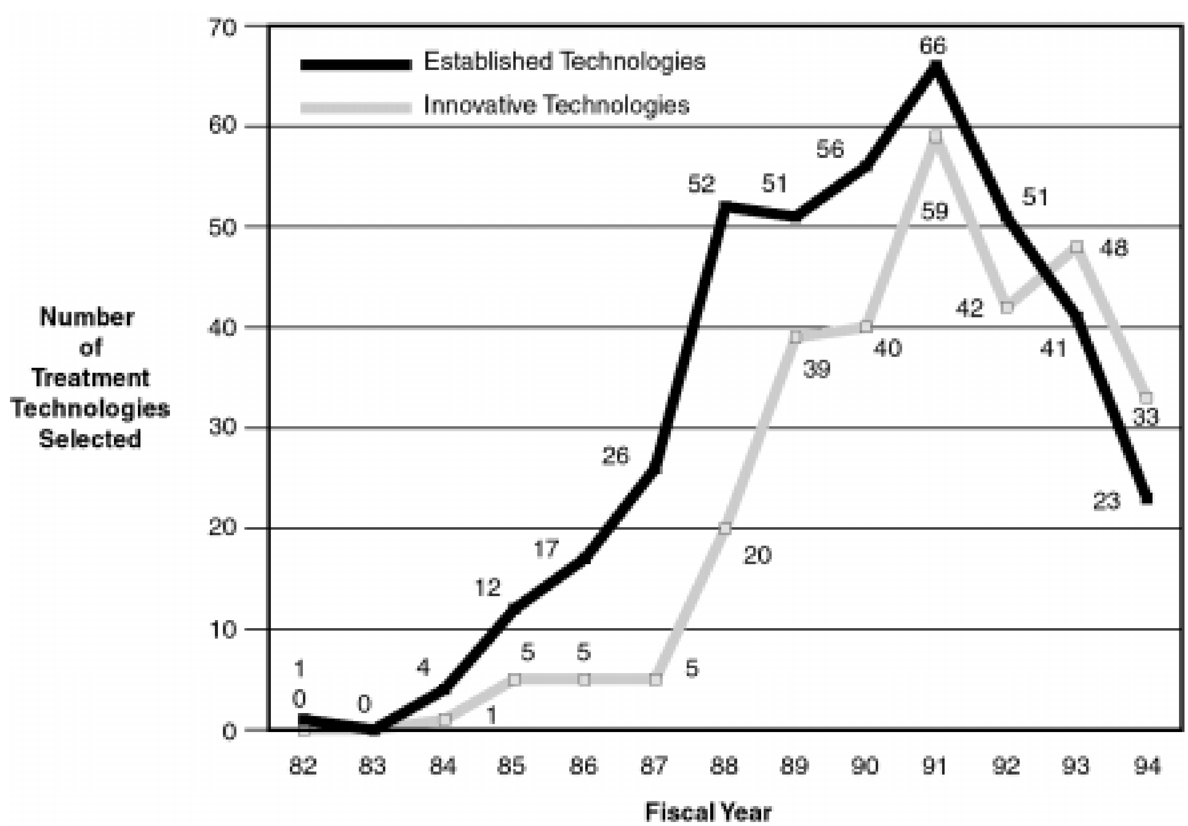


Figure 3. Superfund Remedial Actions: Trends for Three Most Frequently Selected Established Treatment Technologies for Source Control

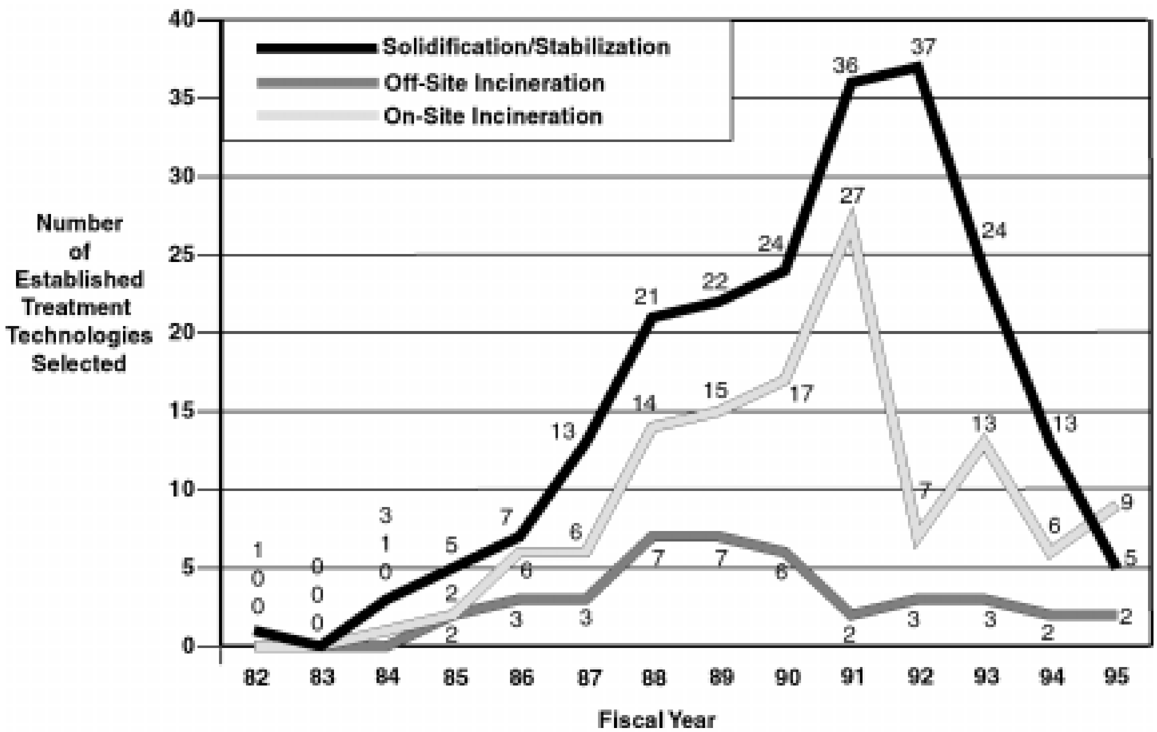
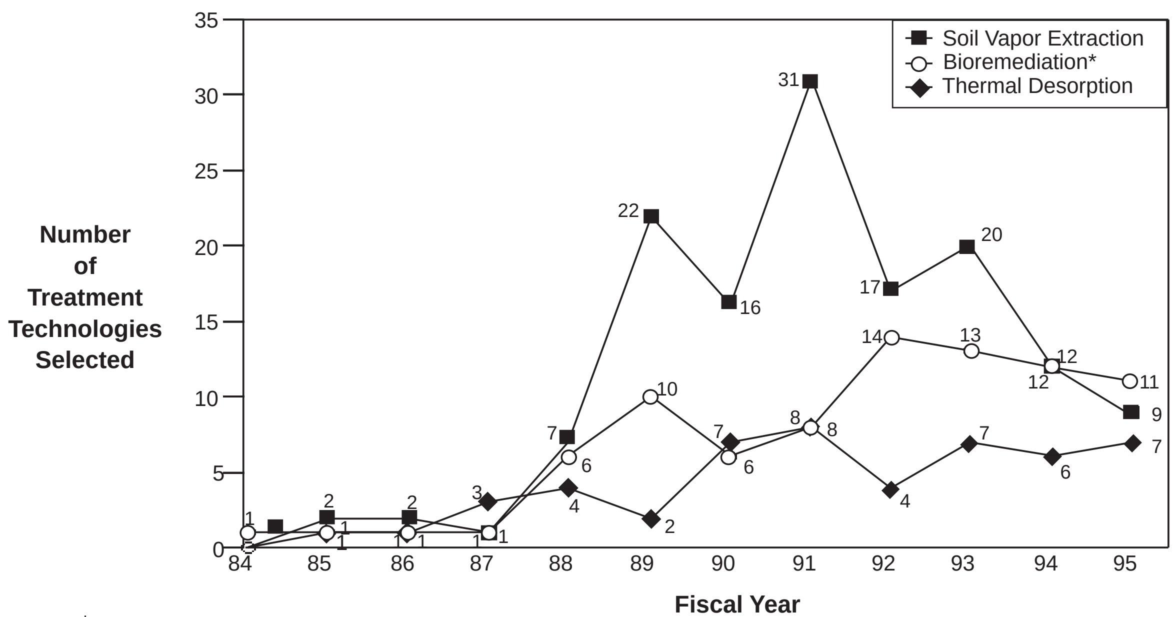


Figure 4. Superfund Remedial Actions: Trends for Three Most Frequently Selected Innovative Technologies



Notes: * Also includes *in situ* groundwater treatment.

Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition),* EPA 542-R-96-010, November 1996.

Figure 5. Estimated Quantities of Soil to be Treated by Innovative Treatment at NPL Sites

Technology	Number of NPL Sites		Quantity (Cubic Yards)		
	Total Sites	Sites with Data	Range	Average	Total
Soil Vapor Extraction	137	118	11 - 6,200,000	250,130	29,515,300
In Situ Bioremediation	26	12	5,000 - 484,000	106,108	1,273,300
In Situ Flushing	16	12	5,200 - 750,000	97,383	1,168,600
Soil Washing	9	8	5,500 - 62,000	23,263	186,100
Ex Situ Bioremediation	43	35	400 - 208,000	34,591	1,210,700
Dechlorination	4	4	700 - 48,000	27,700	110,800
Solvent Extraction	5	5	7,000 - 100,000	27,540	137,700
Thermal Desorption	50	43	250 - 180,000	26,813	1, 153,000
Cyanide Oxidation	1	1			3,000
Contained Recovery of Oily Wastes (CROW™)	1	1			200
Physical Separation	1	1			8,000
Plasma High Temperature Metals Recovery	1	1			65,000
Vitrification	3	1			4,600
Total	297	242			34,836,300

Figure 6. Superfund Remedial Actions: Applications of Innovative Treatment Technologies

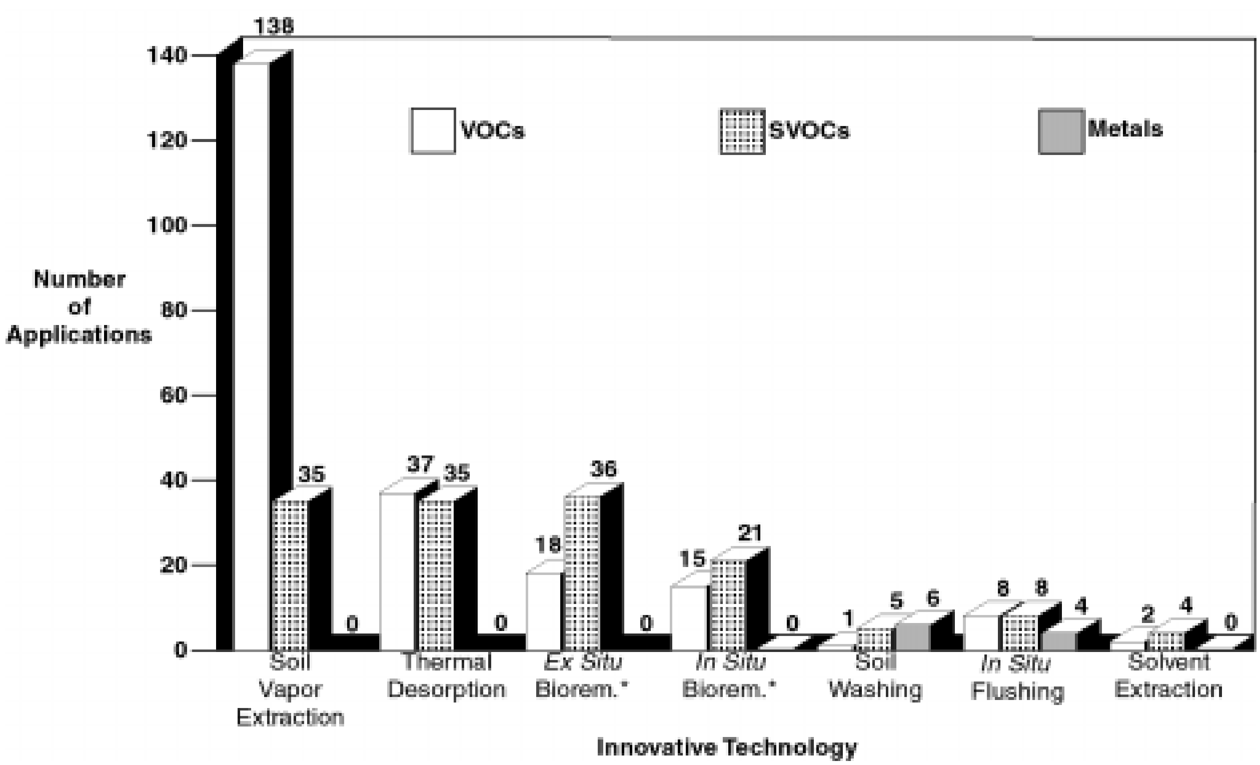
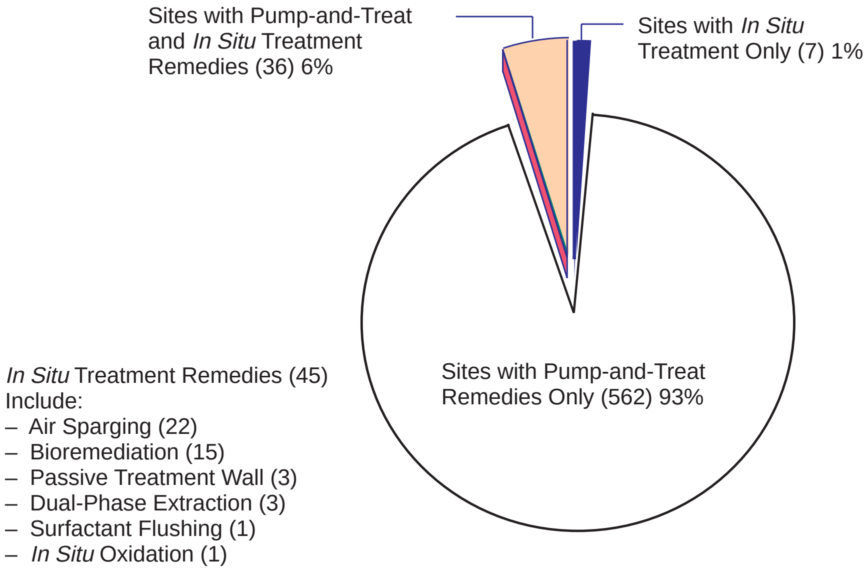


Figure 7. Superfund Remedial Actions: Ground-Water Remedies Through Fiscal Year 1995 (Total Sites = 605)



Note:

- Does not include groundwater sites with nontreatment remedies (*i.e.*, monitoring, institutional controls, alternate water supply, well-head treatment, closing wells, containment, or natural attenuation).

Figure 8. Completed North American Innovative Technology Demonstration Projects

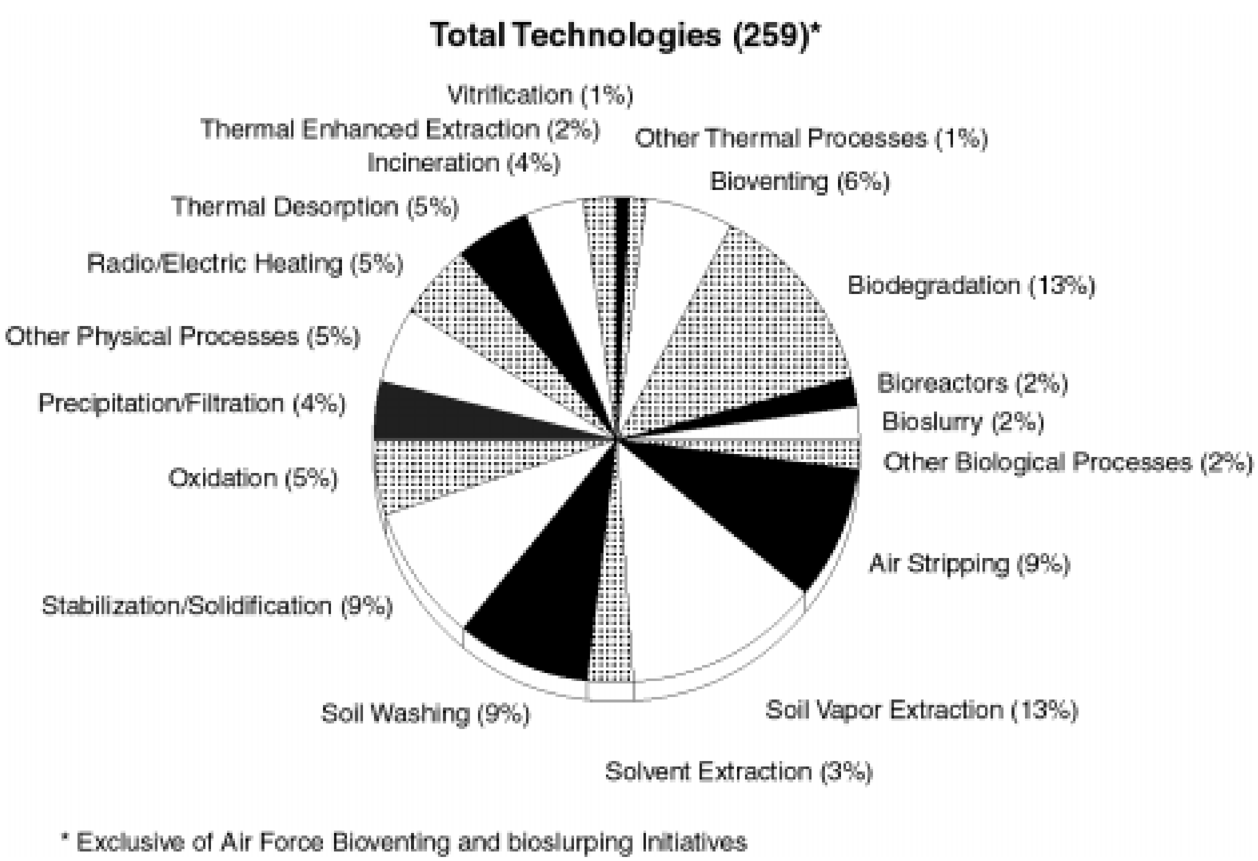


Figure 9. SITE Demonstration Program Technical Categories (Total Participants = 114)

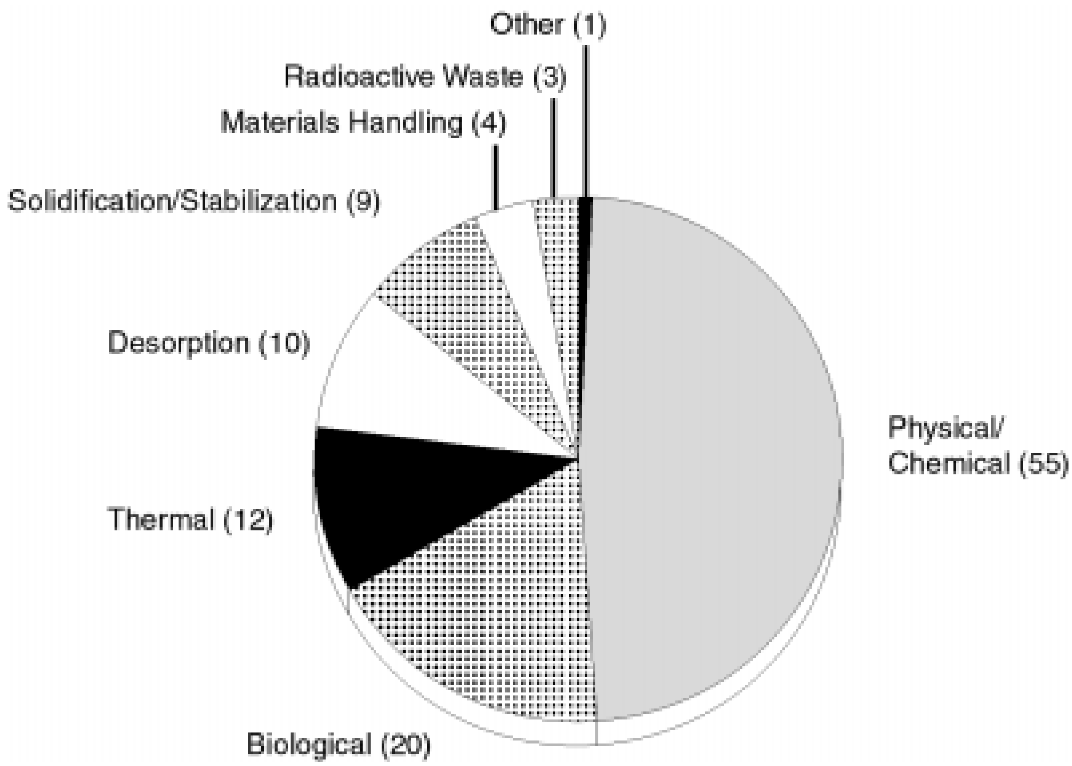


Figure 10. Major Contaminant Subgroups at NPL Sites with RODs

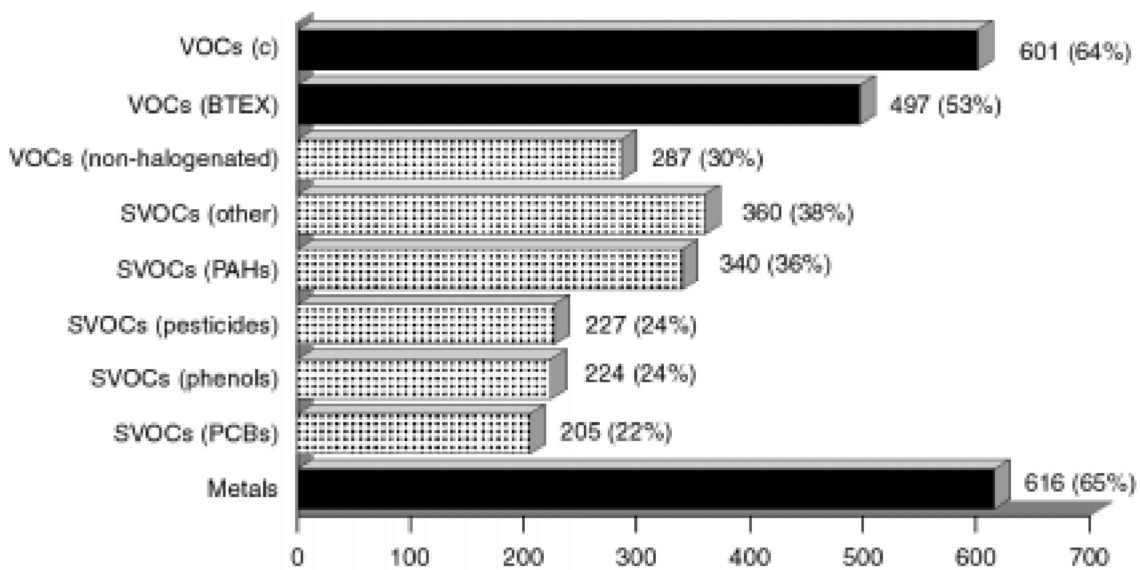
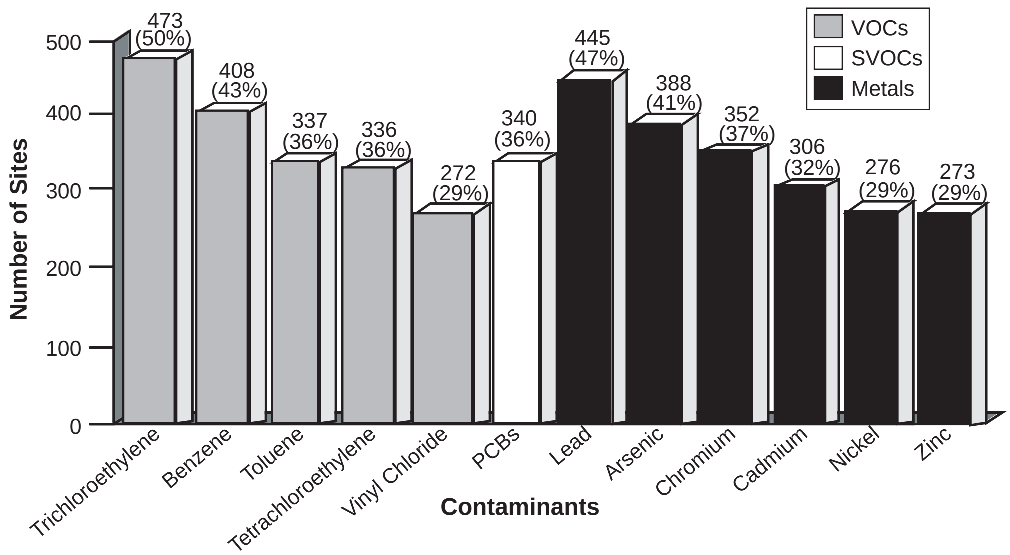


Figure 11. Frequencies of the Most Common Contaminants at NPL Sits with RODs



Notes: Based on data available for 944 National Priorities List sites with fiscal year 1982-1994 Records of Decision (RODs). A site may contain one or more of these contaminants.

Source: U.S. EPA, Office of Emergency and Remedial Response, ROD Information Directory, December 1995.

Figure 12. VISITT 5.0 Technology Types